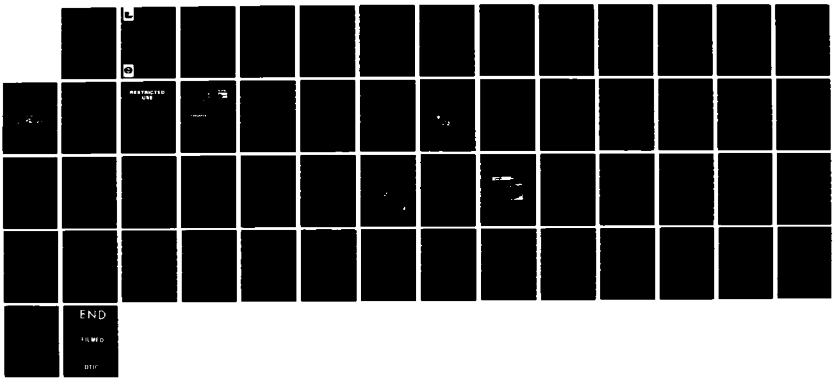
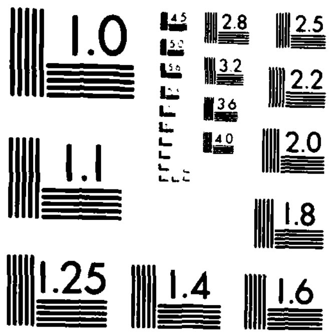
AD-A150 567 MANAGEMENT OF EURASIAN WATERMILFOIL IN THE COLUMBIA RIVER BASIN(U) ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS ENVIRONMENTAL LAB K J KILLGORE 1/1

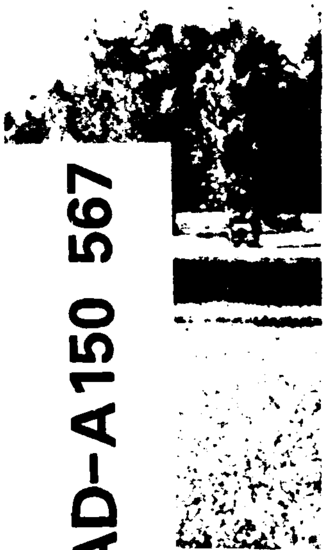
UNCLASSIFIED DEC 84 WES/MP/A-84-7 F/G 6/6 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963 A

US Army Corps of Engineers



AD-A150 567

DTIC FILE COPY

AQUATIC PLANT CONTROL RESEARCH PROGRAM

MISCELLANEOUS PAPER A-84-7

MANAGEMENT OF EURASIAN WATERMILFOIL IN THE COLUMBIA RIVER BASIN

by

K. Jack Killgore, Jr
Environmental Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631
Vicksburg, Mississippi 39180-0631

US ARMY ENGINEER WATERWAYS EXPERIMENT STATION

December 1984
Final Report

Approved For Public Release; Distribution Unlimited

US Army Engineer District, Seattle
Seattle, Washington 98124

DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

ENVIRONMENTAL LABORATORY

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Miscellaneous Paper A-84-7	2. GOVT ACCESSION NO. A150567	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) MANAGEMENT OF EURASIAN WATERMILFOIL IN THE COLUMBIA RIVER BASIN		5. TYPE OF REPORT & PERIOD COVERED Final report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) K. Jack Killgore, Jr.		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Engineer Waterways Experiment Station Environmental Laboratory PO Box 631, Vicksburg, Mississippi 39180-0631		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Aquatic Plant Control Research Program
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Engineer District, Seattle, Seattle, Washington 98124, and DEPARTMENT OF THE ARMY, US Army Corps of Engineers, Washington, DC 20314-1000		12. REPORT DATE December 1984
		13. NUMBER OF PAGES 53
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Available for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Aerial Photography	Selecting Treatment Locations
Aquatic Plant Management	Training
Ground Surveys	Treatment Techniques
Public Awareness	Water Uses

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A recent concept in aquatic plant management is to implement a management program before a problem aquatic plant population creates adverse impacts on water uses. This approach requires a procedure for early detection and subsequent treatment of pioneer problem aquatic plant populations. This report provides an overview of treatment techniques used in aquatic plant management and economic, environmental, and social factors to consider when choosing an appropriate technique for managing Eurasian watermilfoil (*Myriophyllum spicatum* L.) in the Columbia River Basin.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

PREFACE

The information reported herein was based on a Large-Scale Operations Management Test (LSOMT) to evaluate prevention methodology for managing Eurasian watermilfoil in the Columbia River drainage system, which is under the jurisdiction of the U. S. Army Engineer District, Seattle (NPS). The LSOMT was conducted by the Aquatic Plant Control Research Program (APCRP) of the U. S. Army Engineer Waterways Experiment Station (WES) in cooperation with NPS. Funds were provided by the Directorate of Civil Works, Office, Chief of Engineers, through the NPS.

Mr. K. Jack Killgore, WES, prepared this report. Others contributing to the effort and to the contents of this guide were Messrs. A. M. Rekas, S. D. Parris, R. L. Lazor, E. Dardeau, W. Hansen; Ms. E. Hogg; Drs. D. R. Sanders, B. S. Payne, and A. D. Miller of WES; and Messrs. R. M. Rawson and D. R. Bailey of NPS.

This work was conducted under the general supervision of Dr. J. Harrison, Chief, Environmental Laboratory, and Dr. C. J. Kirby, Jr., Chief, Environmental Resources Division, and under the direct supervision of Mr. J. K. Stoll, Chief, Environmental Analysis Group, all of the WES. Mr. J. L. Decell was Manager, APCRP.

Director of WES during the preparation of this report was COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

This report should be cited as follows:

Killgore, K. J. 1984. "Management of Eurasian Watermilfoil in the Columbia River Basin," Miscellaneous Paper A-84-7, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acres	4046.873	square metres
feet	0.3048	metres
miles (U. S. statute)	1.609347	kilometres
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square metres
square inches	6.4516	square centimetres

elements. Manuals, scientific literature, office and field workshops, seminars, and other procedures are used to instruct personnel conducting prevention management.

b. Monitoring. Monitoring is designed to detect problem aquatic plant populations, establish plant population levels and distribution, identify and locate water uses, determine aquatic plant habitat availability, and assess the effectiveness of treatment. Monitoring generally involves the collection and analysis of a combination of ground and aerial survey data.

c. Reporting. Reporting provides systematic procedures for transmitting pertinent monitoring or treatment data on problem aquatic plant populations to management. Reporting includes coordinating the activities with various Federal, State, and local agencies that are interested and responsible for the management program. To plan annual treatment strategies, Federal, State, and local agencies must cooperate in reporting plant population impacts on water uses and plant distributional changes.

d. Public awareness. A public awareness plan informs Federal, State, and local officials and the public on the distribution and growth of problem aquatic plant population, user impacts associated with the problem population, and available treatment methods being considered.

e. Treatment. Treatment programs keep the problem population at a desired level for a specified local environmental, social, or economic situation. Treatment procedures can be grouped into five major categories: chemical, mechanical, biological, environmental management, and integrated.

Purpose and Scope

4. This report presents a systematic approach for managing submersed aquatic plants in the Columbia River Basin. Emphasis is directed towards preventing or minimizing the plants' impacts on important water uses in large riverine systems. Most techniques described in this report were developed for managing Eurasian watermilfoil (*Myriophyllum spicatum* L.). However, these techniques may be applicable to other submersed aquatic plants as well as floating or emergent growth forms.

Rationale

5. Keeping the problem plant populations from proliferating in all water use areas would require a massive effort in a large drainage system because of the reproductive potential of the plants, budget limitations, and

lack of cost-effective treatment options. Thus, treatment locations should be selected based on treatment-related benefits to produce a justifiable procedure for allocating a limited budget and preventing the impacts of the more important water uses.

6. Without treatment the plant population may increase to a level unacceptable to the water user. Then, treatment of higher levels and possibly larger areas would be required to reduce the problem population to an acceptable level. In addition, repetitious treatment over one growing season may be required to reduce higher levels of problem aquatic plant populations. Thus, treating problem populations before they reach higher levels can be cost-effective by avoiding accumulating treatments which may be required later.

Approach

7. Tasks are presented to train involved personnel, conduct a public awareness program, determine aquatic plant and water use locations, conduct ground surveys, and describe a systematic approach to prioritize treatment locations. A general overview of treatment techniques and factors to consider when choosing a technique is also given. When appropriate, examples and limitations of the procedures are provided to put the individual components of the management program in perspective.

PART II: SPECIAL TASKS IN AN AQUATIC PLANT MANAGEMENT PROCEDURE

8. The management procedure is described through a series of sequential tasks. Within each task, a number of steps are described in detail. An overview of the tasks is shown in Table 1. Although each task has a different purpose, they are interrelated. Trained personnel (Task I) are required to meet the objectives of all subsequent tasks. A public awareness program (Task II) is conducted before and after treatment. The maps of the aquatic plant distribution (Task III) are used by the ground survey team (Task V) to help locate problem aquatic plant populations and determine the size of treatment locations. Selecting treatment locations (Task VI) must consider information derived from three other tasks. These include:

- a. The areal distribution of problem aquatic plant populations for each water body (Tasks III and V).
- b. The area encompassing individual water uses (Task IV).
- c. The "intensity of use" for each water use (Task IV).

It is recommended that the entire task sequence be read in its entirety before any individual task is implemented.

Task I: Train Personnel to Meet Management Objectives and Requirements

9. This task discusses procedures to help involved personnel become familiar with aquatic plant identification and ecology, treatment and monitoring techniques, and laws and regulations pertinent to implementation of the management program. This information is used in other tasks to help map aquatic plant distribution, assess potential and existing aquatic plant habitat, and determine the type of treatment required including where and when to implement the treatment.

Step 1: Become familiar with problem aquatic plant management

10. Involved personnel must become familiar with:

- a. Aquatic plant identification.
- b. Aquatic plant habitat requirements and ecology affecting establishment, growth, and reproduction.

c. Aquatic plant treatment techniques including the environmental conditions which may affect treatment effectiveness and compatibility.

d. Aquatic plant monitoring techniques.

Aquatic plants are identified from taxonomic keys or consultation with university botanists or aquatic ecologists. Review of the literature can provide information on specific and general topics for aquatic plant habitat requirements, treatment techniques, and monitoring techniques. Pertinent literature sources include:

a. Automated literature searches on specific aquatic plant subjects. Available from: University of Florida, Aquatic Weed Program, Room 3103 McCarty Hall, University of Florida, Gainesville, FL 32611.

b. Journal of Aquatic Plant Management.

c. Aquatic Botany.

d. Proceedings, U. S. Army Engineer Waterways Experiment Station, Aquatic Plant Control Research Program Annual Review Meeting, Vicksburg, Miss.

e. Technical reports and miscellaneous papers, Aquatic Plant Control Research Program, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

f. "Studies on Aquatic Macrophytes," Province of British Columbia, Ministry of Environment.

g. Aquatics Magazine, Florida Aquatic Plant Management Society.

Step 2: Review laws, regulations, and local ordinances governing the use of alternative treatment techniques

11. Table 2 lists the major Federal laws governing the use of herbicides, the release of biological organisms, and the use of mechanical devices to treat aquatic plants. State and local regulations may also restrict the use of certain treatment techniques.

Step 3: Organize and/or participate in aquatic plant management workshops

12. An aquatic plant management workshop is designed to transmit or receive information for training or education of field personnel and management. Topics covered in training courses include:

a. Aquatic plant identification and population dynamics.

b. Aquatic plant management concepts.

c. Monitoring techniques.

d. Treatment methods for chemical, mechanical, biological, and integrated control.

Activities include lecture, laboratory, and field demonstrations. Table 3 presents an outline of subjects used in previous aquatic plant training courses.

Task II: Conduct a Public Awareness Program

13. Informing the public during the planning and operational phases of the program is accomplished using brochures or signs, utilizing the media, and conducting public meetings. A public awareness program should be planned early in the management program in order to produce the necessary informative literature and to allow public comments on treatment strategy before treatment is implemented.

Step 1: Disseminate information material concerning potential impacts associated with the problem aquatic plant and details of the management program

14. Information material can describe the problem aquatic plants' potential to restrict water uses if left unmanaged (see Table 4) and techniques being considered to manage the problem populations. This type of information is disseminated by preparing and distributing information brochures. An example of a brochure is shown in Figure 1. Table 5 lists further subjects which can be used in the brochures.

15. The media is used for distributing information to a large audience. News releases can be prepared based on similar information found in the brochures and released at appropriate times. Newsletters can be prepared and sent to groups and citizens who have previously expressed interest or potential interest in the program. Audiovisual displays in public places and periodic presentations to interested local organizations can also be used to inform the public on the management objectives and to solicit public support.

Step 2: Conduct public meetings

16. Public meetings allow public input into the management program and are used to inform the public on the management program. Subjects discussed in public meetings are the present distribution of plant populations, potential

EURASIAN WATERMILFOIL

EURASIAN WATERMILFOIL

WHAT IS EURASIAN WATERMILFOIL AND WHY IS IT A PROBLEM?

Eurasian watermilfoil (*Myriophyllum Spicatum l.*) is a perennial aquatic plant which roots itself to lake or river bottom. Milfoil is native to Asia, Africa, and Europe, and was probably brought into the United States on ships coming from these countries. Since its introduction, milfoil has become widespread in Chesapeake Bay, the Tennessee Valley Authority impoundments, Florida, Texas, and the Pacific Northwest. During the spring and summer months, milfoil grows rapidly from roots and can form thick, nearly impenetrable mats of stems and leaves at the water surface. Milfoil can occur in water up to 15 feet and can spread into new areas by fragmentation. Some impacts milfoil has created on the aquatic environment are:

- Restricts boating, fishing, and swimming.
- Blocks water intakes for municipal, industrial, and agricultural uses.
- Depresses land values of waterfront property.
- Reduces habitat for fish and wildlife.
- Creates a health hazard by increasing mosquito breeding areas.

Figure 1. Example of an information brochure (Continued)

WHAT IS BEING DONE TO MANAGE EURASIAN WATERMILFOIL?

A management program has been initiated to prevent milfoil from creating impacts on water uses. The approach involves early detection of milfoil using aerial and ground survey methods, identifying water use areas which could be impacted by milfoil, and initiating appropriate treatment techniques to keep milfoil at a nonproblem level.

HOW CAN EURASIAN WATERMILFOIL BE CONTROLLED?

There are presently four methods for controlling milfoil:

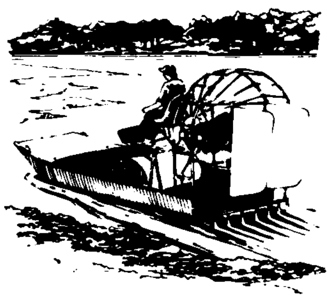
1. **Mechanical methods** include the use of harvesting machines that "mow" the weeds underwater; rototillers or dredges that remove the entire plant; and fragment barriers that inhibit milfoil fragments from moving downstream.

2. **Chemical methods** involve the application of various herbicides which have been approved for aquatic use.

3. **Biological methods** involve the use of a plant-eating fish, the grass carp.

4. **Environmental manipulation methods** include the use of a plastic screening material to reduce the amount of light reaching the plants or water-level fluctuations which expose the milfoil to drying and/or freezing conditions.

Mechanical Harvester



Airboat applying herbicides

The grass carp eating milfoil

Each method has advantages and disadvantages which are considered during the selection process, including environmental compatibility, social impacts, cost, and effectiveness.

WHAT CAN THE INDIVIDUAL BOATER DO?

Milfoil fragments should be cleared from propellers and boat trailers when boats are moved from one launching site to another. If milfoil is identified contact the appropriate agency.

Figure 1. (Concluded)

impacts to water uses, and treatment strategy and costs. Canter (1977) makes the following suggestions for conducting public meetings:

a. Keep data presentations simple.

b. Use simple visual aids (e.g. slides, maps).

c. Discuss project timing.

d. Avoid use of technical jargon.

e. Be familiar with the area.

Step 3: Establish a public quarantine program

17. Public use of water bodies can be a primary cause of the dispersal of problem aquatic plants. A public quarantine program minimizes the public's augmentation of plant dispersal and heightens public awareness of the presence of the problem plant species, its ecology, and the management effort under way. The following methods were used in a public quarantine program in an attempt to stop the spread of Eurasian watermilfoil in the Columbia River Basin:

a. Signs were placed at all public access points warning the public on the hazards of transporting problem plants between water bodies (see Figure 2 for example).

b. Pamphlets were distributed to water users describing actions the public can take to minimize transporting of plants between water bodies.

c. Boat launch and roadside inspection stations were set up to check boats and trailers for viable plants being transported. Dove and Wallis (1981) found that the most common means of dispersal of Eurasian watermilfoil in the Okanogan River in Canada was by boats and boat trailers.

Since there are other means of transporting problem plants between water bodies that cannot be totally eliminated such as disposal of aquarium plants into public waterways (e.g. it is believed that hydrilla was first introduced into Florida public waterways by this means), waterfowl transporting plants, and the natural movement of viable plants through river currents, a public quarantine program alone will not be totally successful in completely stopping the spread of submersed aquatic plants. However, this program has proved to be an excellent means of educating and involving the primary public users of the water in the overall management program.

RESTRICTED USE

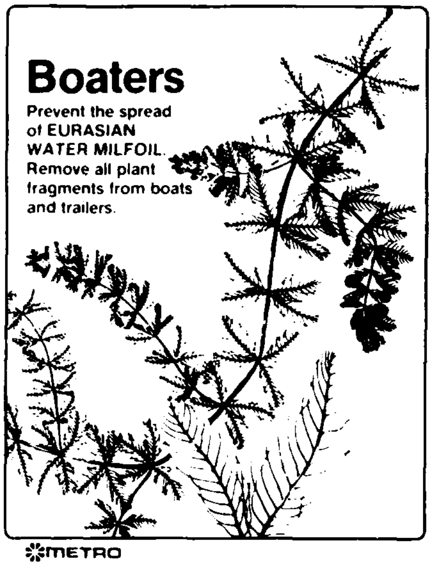
Portions of this lake will be treated for control of aquatic weed growth on ____________________.

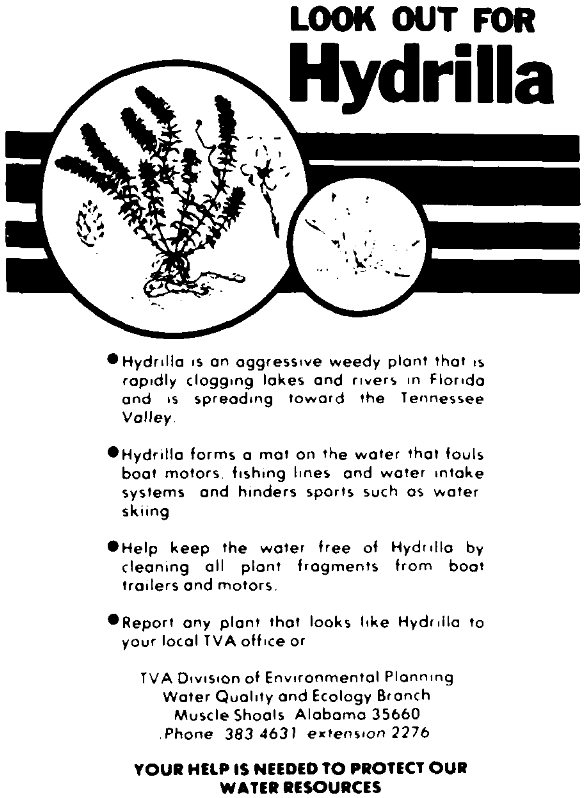
Please note the following water use restrictions within the buoyed areas.

1. **No swimming until ____________________.**
2. **Do not consume any fish caught between ______________ and ______________.**
3. **Treated water cannot be used for irrigation or for agricultural sprays on food crops or for domestic purposes until ______________________________.**

All materials used are registered with the EPA for use in the Aquatic Environment.

Figure 2. Example of information signs (Continued)





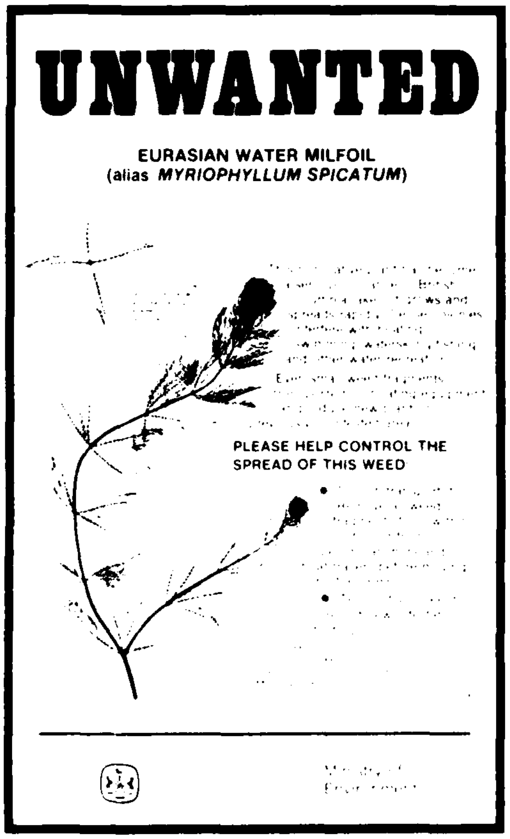


Figure 2. (Concluded)

Task III: Map Aquatic Plant Distribution

18. This task describes the use of aerial photography to locate and map aquatic plant populations and is recommended for large drainage systems. Relatively smaller areas can be mapped from ground survey data only (see Task V, Step 3). The maps are used as an aid in selecting ground survey locations (Task V, Step 1) and can be used as overlays with the water use maps (Task IV) to visually and quantitatively assess the co-occurrence of the problem populations and water uses. Once the initial map of the aquatic plant distribution and shoreline is made from interpretation of aerial photography, ground survey data are used to annually update distributional changes in the problem plant population.

Step 1: Obtain aerial photography

19. The procedure for obtaining the aerial photography includes identifying the areas to be photographed, scheduling the photomission, and determining the scale and type of photography to be used. The water bodies to be surveyed are identified according to their geographical location, size, and drainage system. Determine the size and configuration of the water bodies from U. S. Geological Survey (USGS) quadrangle maps or from existing photography taken by various agencies (e.g., U. S. Department of Agriculture, U. S. Forest Service, or U. S. Department of Interior). It is recommended that the photographic (and ground) survey encompass areas other than those of suspected or known populations of the problem aquatic plant. As was the case in Columbia River Basin, most problem aquatic plants can disperse and become established far from the source population.

20. The photomission should be scheduled for a time period when the sun does not create tree shadows on the water. Some water bodies cannot be aerial photographed for use in detecting aquatic plants due to tree-covered shorelines or turbid waters. If this is the case, all monitoring activity will have to be accomplished through ground surveys (see Task V). The aerial photomissions should also be scheduled for a time period when the plant population is most visible. Most aquatic plants reach their maximum biomass density in late summer or early fall.

21. The distributions of most aquatic plant populations are mapped from 1:12,000-scale photographs (Leonard and Payne 1984; Dardeau and Lazor 1982). Aerial photographs at a 1:6,000-scale are more expensive to obtain and scales

higher than 1:12,000 (e.g., 1:24,000) do not provide adequate resolution to detect and accurately measure plant abundance. Submerged plants are best detected from true color photography while color infrared film should be used to detect emergent and floating plants. Both films will produce rolls of color transparencies used for photointerpretation and mapping. For more specific information, see Leonard and Payne (1984) and Dardeau and Lazor (1982).

Step 2: Interpret photography
and map aquatic plant distribution

22. Once the photography is obtained, the location of the aquatic plant populations should be mapped relative to shoreline features. This is done by placing the roll of color transparencies on a light table and placing a clear drafting plastic such as mylar on top of the color transparencies. The shoreline is then traced from the photographs onto the drafting plastic. This line drawing of the shoreline is referred to as a base map. Landmarks and river miles are indicated on the base map as a reference for ground survey teams. If the area photographed is a wide water body and a single flight line does not encompass both shorelines, a photomosaic may be required in order to accurately trace the shoreline and aquatic plant populations.

23. The boundaries of the aquatic plant populations are traced in the same manner as the shoreline. The plant population can be traced directly on the base map or on an overlay if the base map needs to be kept clean for future use. The aquatic plant population growth forms* can be identified from the photographs according to the following descriptive features (Leonard and Payne 1984):

- a. The shape of the plant population.
- b. The size of the population.
- c. The pattern of the plant population.
- d. The color of the plant population.
- e. The texture (visual impression of roughness or smoothness) of the plant population.

---

* Aquatic plant growth forms include:

- Emersed - Rooted to the substrate with their leaves and/or stems extending above the water surface (e.g., alligatorweed, American lotus).
- Floating - Free-floating plants not rooted to the substrate (e.g. waterhyacinth)
- Submersed - Underwater plants rooted to the substrate and often growing to the water surface (e.g. milfoil, hydrilla).

The accuracy of the photointerpretation can be determined during the ground survey (Task V). Most photography does not allow for specific species identification. If the problem aquatic plant population occurs among nonproblem aquatic plant populations of the same growth form (e.g., all species are submersed), then ground survey data must be taken at those locations which delineate the boundaries between problem and nonproblem populations in order to determine the relative contribution of the problem aquatic plant population for each water body. See Task V, Step 3, for a method of mapping aquatic plants on the ground. Figure 3 shows a map of the distribution of submersed aquatic plant populations interpreted from 1:12,000 color aerial photographs. An original scale map can be photo-mechanically copied on mylar and the scale can be varied to fit individual needs.

Task IV: Inventory Water Uses

24. All water uses in the area of interest must be inventoried to identify current or potential aquatic plant problem areas. This task describes procedures to identify water uses with a general discussion on aquatic plant impacts to water uses, characterizes water uses according to their "intensity of use," and maps the location of water uses. Once the maps of the water use locations and the aquatic plant distribution are completed, a procedure is given to determine the areal extent of each water use and the areal extent of the plant population within each water use. The co-occurrence of both the water uses and the problem aquatic plant population will be used in Task VI to select treatment locations.

Step 1: Identify and characterize water uses

25. To begin, water uses need to be inventoried according to type (e.g. irrigation, recreational boating) and associated impacts from aquatic plants. Water use types have been inventoried by reviewing existing data sources such as reconnaissance reports, advertising brochures, literature from Federal and State parks, and hydrological reports, as well as correspondence with the Chamber of Commerce, marina operators, irrigation districts, and local landowners. Also, several Corps of Engineer Divisions publish water resource development reports which contain information on water uses (e.g. Water Resource Development by the U. S. Army Corps of Engineers in Washington, D. C.). During

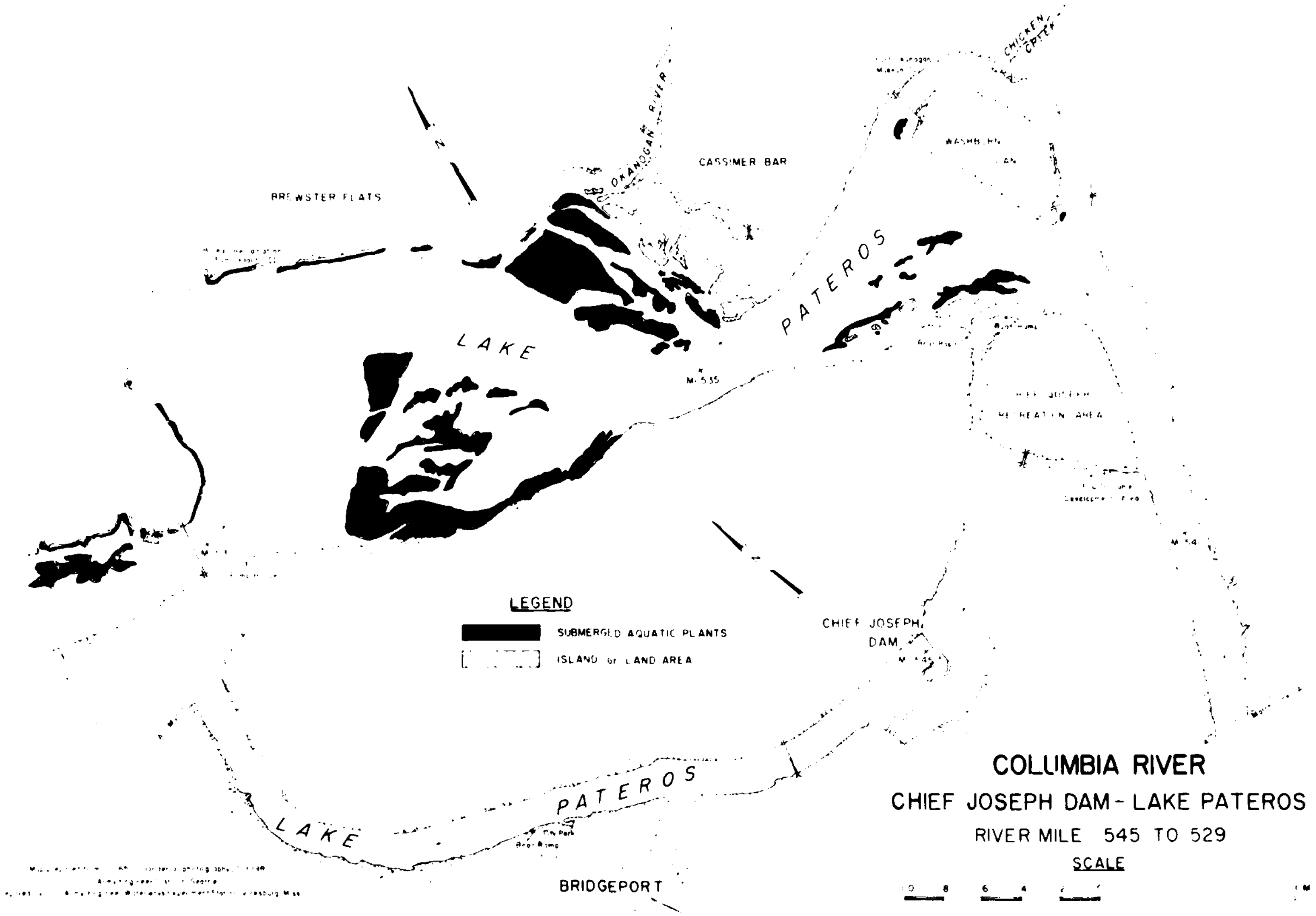


Figure 3. Example of map showing distribution of submersed aquatic plants

the inventory, the aquatic plant impacts on each water use should be identified from information provided by the user. In addition, a review of Table 4, which lists types of water uses with associated aquatic plant impacts according to plant growth form, will help to qualitatively describe the impact on the water use. During the ground survey (Task V), it must be verified that all water uses have been identified. However, an initial inventory of water uses should be completed before the ground survey to help determine survey locations (see Task V, Step 1).

26. Each water use identified must be characterized by its current intensity of use (i.e. density of users over the time period when the plant can interfere with the use). This information must be considered in the procedure to select treatment locations (see Task VI). The intensity of use must be classified seasonally (e.g. January-March, April-June, July-September, October-December) in order to relate the time period that the use is most susceptible to aquatic plant impacts and to express the intensity of use either in relative terms (e.g. high, medium, low/season) or by numerical terms (e.g. 1000 visitors/season for a recreational area). The intensity of use is determined by canvassing the water uses from existing data sources described in the previous paragraph or surveying the user population using methods such as mail out questionnaires, on-site surveys, or traffic measurement (Babbie 1973; Mischon and Wyatt 1979).

Step 2: Map water uses

27. For future reference, as each water body use is identified, their location and boundaries must be indicated on a map that encompasses the water use. Ideally, a map of the shoreline traced from the aerial photography obtained in Task III should be used. This will provide identically scaled maps of both the water uses and the aquatic plant distribution which can be used as overlays. The aerial photography and USGS quadrangle sheets can be used to specifically locate water uses once the general location has been determined from other sources.

28. Denoting water uses on the maps can be indicated in many ways depending on individual preference. Lawrence (1971) suggests that mapping of the topographic details can be accomplished by using linear methods, shading or color tones, symbolized information, or written information in words, abbreviations, numbers, etc. For example, water uses may be indicated by a number and the number placed on the map corresponding to its location. Water

use areas that encompass large areas, such as waterfowl feeding grounds, can be outlined and the number placed inside the boundary. Figure 4 shows an example of a water use map which can be used as overlays with the aquatic plant distribution map previously shown in Figure 3.

Step 3: Determine the area encompassed by the aquatic plant populations within each water use

29. The areal estimates of each water use and the problem aquatic plant populations within the boundaries of each water use must be recorded by individual water bodies for use in the procedure for selecting treatment locations (see Task VI, Step 2). To measure the area, an exact scale of the base map must be determined. This is done by measuring the distance between two reference points on the base map and comparing this value to the same measurement from a rectified map with existing scale (e.g., USGS quadrangle maps) according to the following equation:

$$\frac{\text{Actual Ground Distance (mm)}}{\text{Base Map Distance (mm)}} = \text{Map Scale Ratio (e.g., 1:12,000)} \qquad (1)$$

If a rectified map is not available to determine the actual ground distance, the measurement must be taken during the ground survey (Task V). Area measurements can be made using the dot grid method (Dardeau 1983). Place a Bruning areaographic chart randomly over the aquatic plant populations and the water use area. The transparent chart is divided into grids containing a random distribution of dots. Count each dot within the boundary and every other dot falling on the boundary. Multiply the total number of dots counted by a published area equivalent factor to estimate the total area of the plant population, using the following equation:

$$A = \text{No. of dots} \times SF \qquad (2)$$

where

A = area, acres

SF = published aerographic scale factor corresponding to map scale, e.g., 1:12,000 = 0.159420

The dot grid method is inexpensive and will yield a 97 percent accuracy provided that the map areas are 12 in.^{2} or more.* If the plant populations or

* A table of factors for converting U. S. customary units of measurement to metric (SI) is presented on page 3.

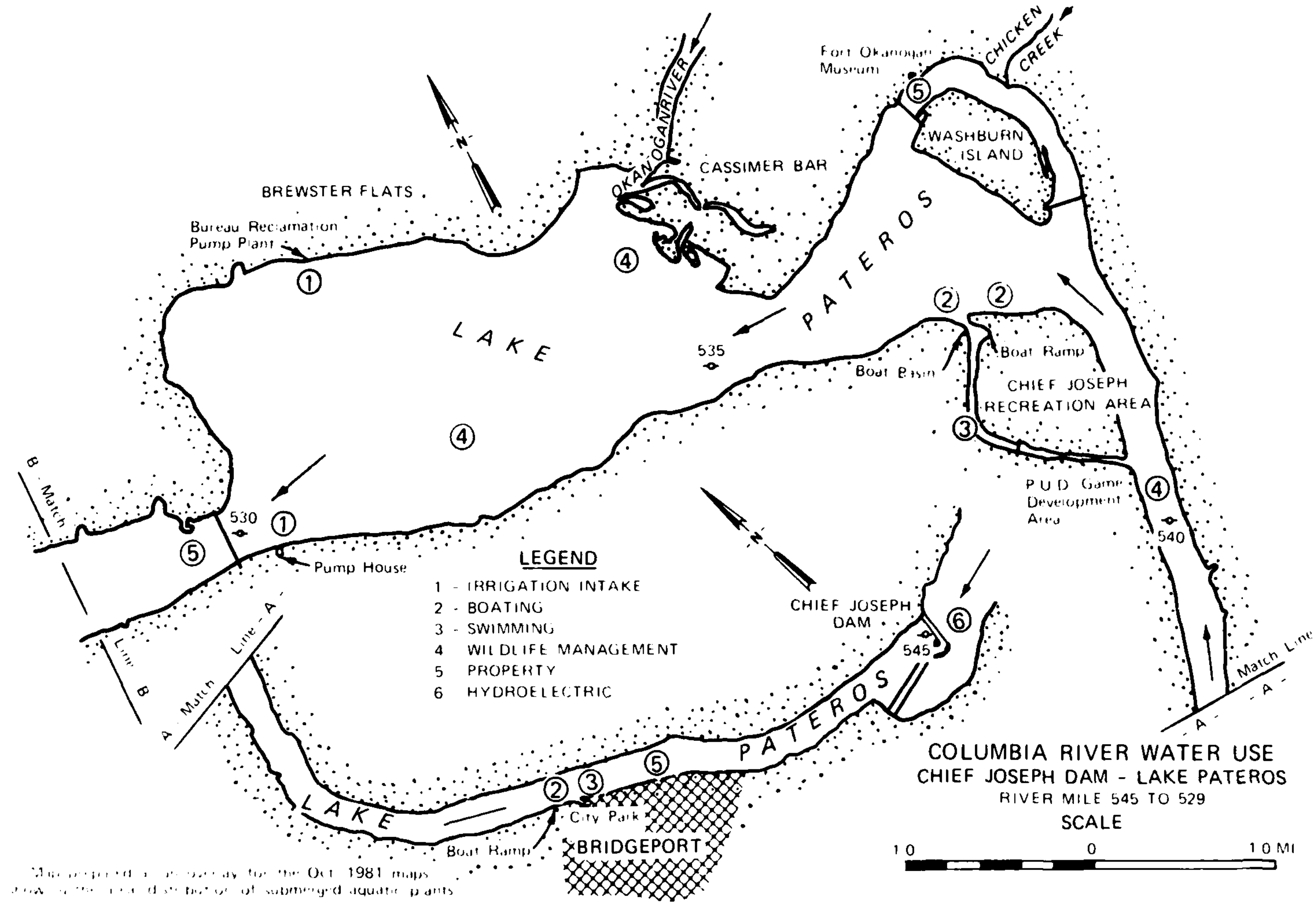


Figure 4. Example of water use map

water use areas are less than 12 in.^{2}, you may cut and piece together mapped boundaries of the small sites to obtain the 12 in.^{2} or you can enlarge the small sites photographically to 12 in.^{2}. See Lawrence (1971) for descriptions of other area measurement techniques (e.g., planimeter).

Task V. Conduct Ground Surveys

30. Ground surveys provide periodic assessments of the problem aquatic plant location and population density, as well as information on water body uses, aquatic plant habitat availability, treatment effectiveness, and photointerpretation verification. Most important, positive identification of aquatic plants can only be made on the ground. At the minimum, annual ground surveys must be made in order to detect problem aquatic plants before they impact on water body uses. Record all data on a data sheet for future reference (Figure 5).

Step 1: Determine ground survey locations

31. Ground survey locations must be representative of the entire area of interest and include as much of the area as possible depending on temporal or fiscal constraints. Locations should be chosen to maximize water use/aquatic plant co-occurrences.

32. Ground survey locations should include:

- a. Areas of aquatic plants identified on the photography which have the same growth form as the problem species (to check photointerpretation accuracy).
- b. Boat basins or ramps.
- c. Shallow flats.
- d. Water inlets.
- e. Beaches.
- f. Waterfowl feeding grounds.
- g. Water uses which are currently "susceptible" or contain problem aquatic plant populations.

Step 2: Determine time of ground survey

33. The ground survey should be conducted near the time of the photomission for accurate verification of problem plant locations on the aquatic plant distribution maps. In addition, ground surveys (and photomissions) must

RECORD OF GROUND SURVEY FOR AQUATIC PLANTS

SURVEY SITE						
DATE/TIME	DRAINAGE SYSTEM	WATER BODY	STATE/COUNTY	SURVEY SITE POSITION	SURVEY PERSONNEL/AGENCY	OTHER

AQUATIC PLANTS						
AQUATIC PLANT SPECIES	LIFE CYCLE STAGE	AREA OF OCCURRENCE (SQ FT)	DISTRIBUTION	VOUCHER NO.	OTHER	TOTAL AREA OF ENTIRE PLANT COMMUNITY (SQ FT)

HABITAT DESCRIPTION						
WATER DEPTH (FT)			SUBSTRATE TYPE	TURBIDITY (JTU)	WATER VELOCITY (FT/SEC)	OTHER
MINIMUM	MAXIMUM	AVERAGE				

WATER USE				
TYPE	PERIOD OF USE	SURFACE AREA ENCOMPASSED BY WATER USE (SQ FT)	IMPACTS CAUSED BY AQUATIC PLANTS	COMMENTS

Figure 5. Example data sheet used in ground surveys

be timed so that the aquatic plant populations are highly visible (maximum abundance) and the reproductive structures are intact so positive species identification can be made. Ground surveys should also be conducted following treatment to assess the degree and duration of changes in plant populations.

Step 3: Collect appropriate ground survey data

34. The minimum ground survey data to collect include:

a. Aquatic plant species currently present in the area of interest.

b. Areal contribution of the problem aquatic plant population in each water use area.

c. Limiting growth factors.

d. Descriptive water use information.

35. The aquatic plant species present in the area can be partially determined prior to the ground survey by reviewing general botanical surveys of the area, conducting herbarium searches, or corresponding with managers of a particular water body. During the ground survey, personnel trained in aquatic plant identification must be present to determine aquatic plant species. It is recommended that the ground survey team collect, preserve, voucher, and store specimens for future reference from each water body surveyed.

36. The areal extent of all the problem aquatic plant populations within each water use area must be indicated on a map or recorded on data sheets (if the photointerpreter was unable to delineate between problem and nonproblem plant populations). This information can also be used to determine the size of treatment locations and to check photointerpretation accuracy of delineating between growth forms. The boundaries of each problem population can be visually estimated and drawn on the aquatic plant distribution maps or USGS quad sheets. A more accurate method is to place buoys along the corners or periphery (if oval shaped) of the problem population, determine the distance between buoys using a lense displacing optical rangefinder, and indicate the boundaries on the aquatic plant distribution maps or USGS quad sheets. In selected ground survey locations, the area of all different growth forms of aquatic plant populations should be measured relative to obvious shoreline features, the accuracy of the photointerpreted maps in these areas should be checked, and this information should be extrapolated to the entire area of interest to make any required changes.

37. Habitat data should be collected that indicate limiting and nonlimiting factors (e.g. water depth, water velocity, substrate) of currently established problem plant populations (see Killgore and Payne 1984) for field instrumentation used in the collection of aquatic plant habitat data). Factors limiting the growth of problem aquatic plants are poorly understood (Barko 1982), thus field personnel must determine which factors to measure based on the existing conditions where the problem population is established and from their own training background. The habitat data are then compiled and the average of each determined. Then, this information is extrapolated to the entire area of interest in order to determine the predicted extent of establishment by the problem population based on its growth requirements. For example, if Eurasian watermilfoil was not found in water greater than 20 ft in depth, then the potential area of establishment could be determined by marking the areas of suitable water depth on contour maps or navigational charts and calculating the area using area measurement techniques. This information can also be used to help determine treatment locations based on predicted conditions.

38. Water use information required has been discussed in Task IV. Each water use must be characterized by its "intensity" of use, area encompassing the water use, and aquatic plant impacts on the water use. By canvassing each water user, most of this information can be obtained either before or during the ground survey.

Task VI: Select Treatment Locations

39. In large water bodies such as the Columbia River, problem aquatic plants can establish throughout all available habitat in a relatively short time. Although the level of the plant populations may be minimal during initial establishment, the area requiring treatment may be quite large if maximum reduction of the plant population is to be attained. Due to a lack of budgetary resources or treatment options, elimination of all pioneer populations of problem aquatic plants will usually not be feasible. As a result, treatment locations must be prioritized according to the benefits derived from keeping the plant populations at nonproblem levels. This task describes five considerations which can be made to prioritize treatment locations. These include the co-occurrence of problem aquatic plant populations and water uses,

relative location of the problem population outside the water use, growth form of the problem species and potential area for establishment, intensity of impacted water use, and national, regional, and local importance of the use.

Step 1: Identify co-occurrence of problem aquatic plant populations and water uses

40. Using the maps of aquatic plant distribution, maps of water uses, and the ground verification of both, maps (or overlays) can be made of the co-occurrence of the problem aquatic plant populations and water uses. Once mapped, these form the "group" of sites that must be considered for treatment. Using the information derived from Task IV, Step 3, the problem aquatic plant population surface area within a water use can be divided by the surface area encompassed by that respective use and the results listed. For example, if the areal estimate of the problem aquatic plant population within a recreational boating area was 5 acres and the areal estimate of the boating area was 10 acres, then the quotient would be 0.5. This information will provide a quantitative relationship between water use area and the plant population area for each water use in the area of interest.

Step 2: Rank water uses according to the quotient of the problem aquatic plant population area over the water use area

41. In this step, a numerical rank from 0 to 1 is denoted for each water use based on the value of the quotient. The higher the quotient, the higher the rank. Multiple uses in the same area should receive the highest rank. An example of this procedure is shown in Table 6.

Step 3: Select treatment locations according to the rank of the water uses and other site-specific considerations

42. The ranking procedure described in Step 2 provides an objective consideration using current information to aid in selecting treatment locations when the problem population has established in the water use area. However, other considerations must be addressed for current and predicted situations when making final selections for treatment locations. These include the relative location of the problem population outside the water use area, the growth form of the problem species and potential area for establishment, the intensity of use, and the national, regional, and local importance of the use.

Each management area is unique. As a result, discussion is provided only for these considerations. Those personnel involved in making treatment location selections must weigh each consideration separately for each water use in order to provide a holistic view of the benefits the treatment will have on each water use. Then the inherent value of one water use in relation to another can be made in order to select final treatment site locations.

43. Relative location of the problem population outside the water use area. If the problem populations are adjacent or upstream of a water use, then those populations may be targeted for treatment to avoid future establishment of the problem population in the water use area and subsequent adverse impacts to the water use. An examination of the aerial photography and ground survey data can provide distributional information between water uses and the problem plant population.

44. Growth form of the problem species and potential area for establishment. A specific water use will be affected at varying levels depending on the type of aquatic plant. A submersed aquatic plant such as Eurasian watermilfoil could clog trash racks at hydroelectric projects or irrigation water intakes, whereas it is unlikely that a floating plant such as waterhyacinth would. However, both submersed and floating aquatic plants could impede boating navigation. By examining Table 4, one can assess potential impacts of a particular growth form to the water use. The habitat available in the water use area for establishment by the problem population must also be considered. For instance, a submersed plant will be limited by depth and thus the deeper waters in a water use will remain unaffected; but a floating plant can occupy the entire water surface regardless of depth. The ground survey information can be used to help assess the potential habitat available.

45. Intensity of use. Using the information obtained in Task IV, Step 2, the current intensity of use for each water use during the time period when the problem population could have an effect should be listed. It should be determined whether or not displacement of the water use due to the existence of the problem populations can occur with little effect on the intensity of use. For example, recreational boating can be displaced from an area where aquatic plants are impeding navigation to an area relatively void of aquatic plants (i.e. an acceptable substitute use) with little change in the number of boats on the water body. However, if there are no substitute areas for the water use, the intensity of use would be affected and subsequently may require treatment.

46. National, regional, and local importance of the use. Each use must be classified according to its national, regional, and local importance. This is usually associated with the perturbations of cost-sharing programs to finance treatment. The users investing in a cost-sharing program would expect the treatment locations to coincide with their respective water use locations. However, their willingness to participate does not necessarily indicate a desirable Federal investment. Likewise, the absence of a cost-sharer may, in some instances, reflect the inability of the market place to provide a mechanism for project beneficiaries to participate in cost-sharing. Thus, treatment location selection must reflect both the source of the money and the national, regional, and local treatment-related benefits.

PART III: TREATMENT OF PROBLEM AQUATIC PLANTS

Selection Criteria

47. Treatment technique selection should be based on treatment objective, environmental and administrative considerations, and treatment costs.

Treatment objective

48. A treatment objective is a quantitative description of the extent and duration of plant reduction desired. For example, a submersed aquatic plant population has recently established in a recreational boating area and could impede navigation of recreational boats which operate out of a marina. The marina operator defines the following treatment objective for a specified area: no submersed plants from the water surface to 4 ft below during the months of June through September. The water user or the resource manager will usually be required to define a treatment objective. The treatment objective will usually incorporate qualitative and quantitative factors into the definition. If quantitative information on cause/effect relationships between water uses and levels of aquatic plants is unavailable for a particular water use, then the treatment objective must be estimated. Those defining a treatment objective must realize that current treatment techniques can be very effective but few, if any, completely eliminate the plant population and few provide long-term reduction. Also, aquatic plants benefit the aquatic environment (e.g. provide habitat for aquatic organisms, stabilize bottom sediments, regulate nutrient availability); these benefits should be considered when defining a treatment objective (see Sculthorpe (1967), Penfound (1956), Mulligan (1969), and Muzik (1970) for a discussion on the benefits of aquatic plants).

Environmental and administrative considerations

49. Environmental factors which may influence the effectiveness or compatibility of a treatment in a specific geographical area must be considered before selecting a treatment technique. These factors include water movement, water depth, water quality parameters, relative abundance of the plant population, size of the area requiring treatment, obstructions in the water, climatic factors, relation to the plant life cycle, and impacts to nontarget aquatic organisms (Dardeau and Hogg 1983). Administrative requirements of the treatment related to the domestic and commercial use of the water must also be

considered. For example, the location of domestic or irrigation water intakes relative to a herbicide treatment location must be determined, or permits may be required before a dredge or herbicides can be used to treat the problem population. Table 7 lists site variables that may affect the compatibility and effectiveness of a treatment technique according to the three major treatment categories--chemical, mechanical, and biological.

Treatment costs

50. The cost factors of a treatment include:

a. Operational costs--labor, herbicide, gas, etc.

b. Environmental monitoring costs--herbicide residue levels in the water, etc.

c. Administrative costs--permits, locating water intakes, etc.

d. Capital and recurring costs of equipment (if the work is done in-house).

e. Cost of treatment repetition.

See Mitchell (1979) for a further discussion on treatment costs. The cost of each factor must be determined for each alternative treatment technique. The cost of the treatment is also a function of the treatment objective. The treatment objective identifies the desired effectiveness of the treatment for a specified water use or area and the cost is usually higher per unit area as an increase in plant reduction is desired. Hypothetical examples showing variations in the costs of different treatment techniques for different treatment objectives and social factors are given in Table 8. This table does not consider the capital or recurrent costs of the required equipment, the annual amortization of the equipment, or the environmental factors which may influence treatment effectiveness or compatibility (see Table 7). This table simply points out that tabulating the cost of the various criteria allows consideration of all the relevant factors affecting the decision.

Available Techniques

51. An inventory of all available alternative treatment techniques must be made in order to select a technique appropriate for each water use. Table 9 lists alternative treatment techniques which have been used in operational management of aquatic plants. This list includes chemical, biological, mechanical, and environmental techniques but should not be considered all-inclusive.

52. A review of alternative treatment techniques is given below.

Chemical

53. If problem populations of submersed aquatic plants are growing in flowing water, liquid herbicide formulations should be used in conjunction with adjuvants (e.g. polymers or inverting oil) or granular herbicide formulations to enhance the contact properties of the herbicide to the plant and reduce dispersal of the herbicide away from the treatment area (Baker et al. 1975, Bitting 1974, Wortley 1977, Killgore 1984).

54. Problem aquatic plant populations of low density (<1000 g/m^2 wet weight) require lower application rates of a conventional herbicide or herbicide/adjuvant mixture (see Killgore 1981, 1984), thus reducing the cost and possible environmental damage.

Mechanical

55. Maximum removal of submersed aquatic plants is obtained using a diver-operated dredge (Figure 6) and hand-pulling. The costs of the diver

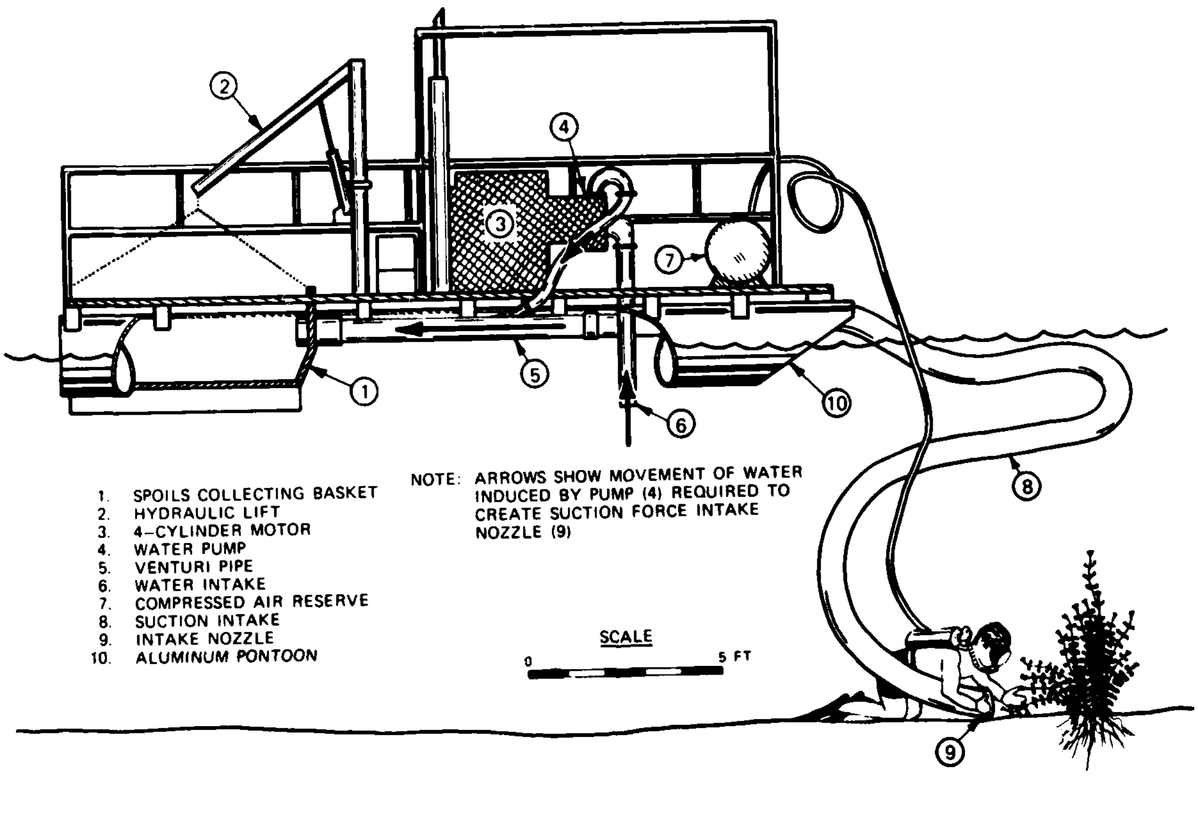


Figure 6. Schematic side view of diver dredge (from "Studies on Aquatic Macrophytes," Ministry of the Environment, Province of British Columbia)

dredge and hand-pulling methods are proportional to the treated area (Figures 7 and 8, respectively) and both are relatively costly on a per-unit-area basis compared to chemical treatments (Dardeau and Lazor 1982, Killgore 1982). Thus, these techniques should only be considered for small, high-use areas.

56. Mechanical harvesting has a short-term effectiveness on submersed

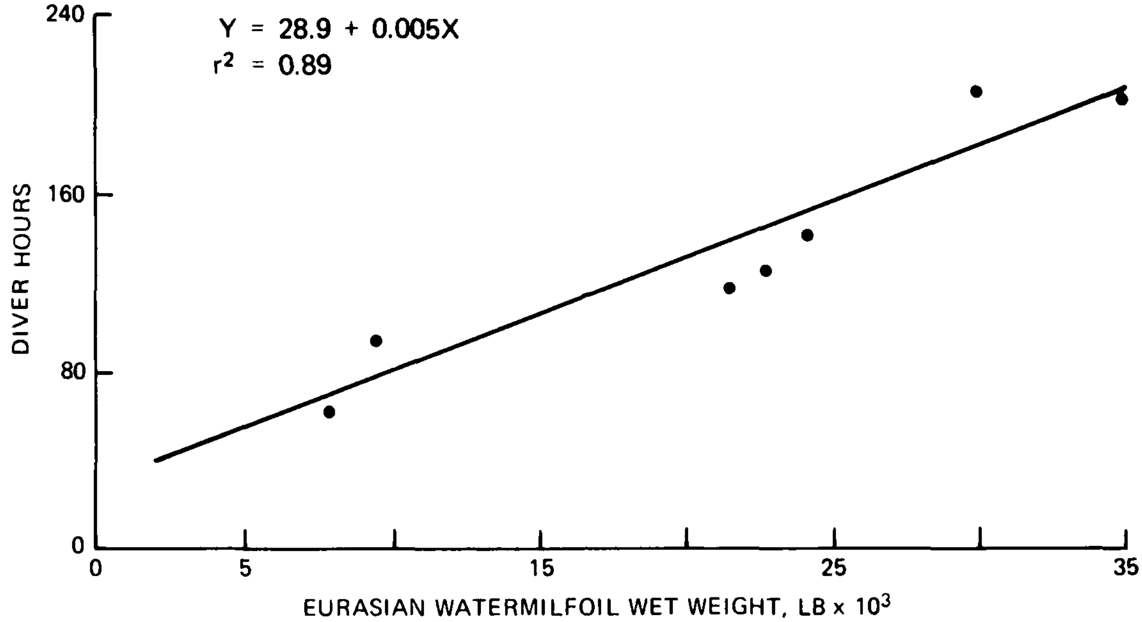


Figure 7. Diver-dredge harvesting time for submersed aquatic plants

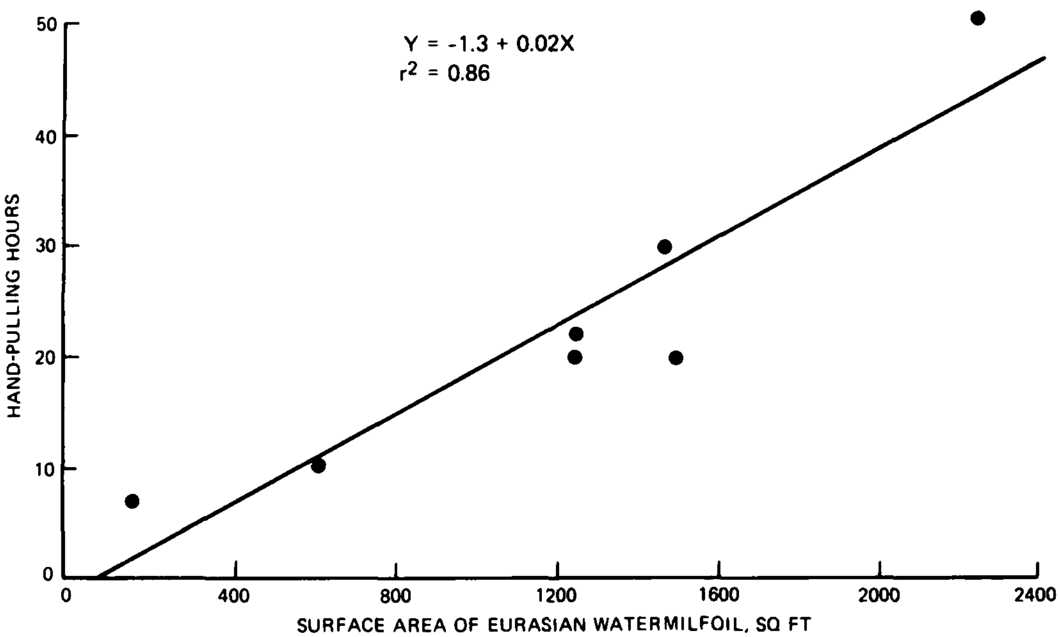


Figure 8. Hand-pulling harvesting time for submersed aquatic plants

aquatic plants and multiple harvests in one season and over two seasons have little carry-over effect on regrowth (Perkins and Systma 1982). However, mechanical harvesters will provide immediate relief in the treatment area (as will most other mechanical treatment techniques), and are relatively cheaper than a diver dredge.

57. A barrier can be positioned across a river or a narrow constriction of a lake to prevent or retard downstream dispersal of viable propagules of a problem plant (Newroth 1979) from established populations to nonestablished areas (Figure 9). However, a barrier will not completely eliminate dispersal (Dardeau and Lazor 1982).

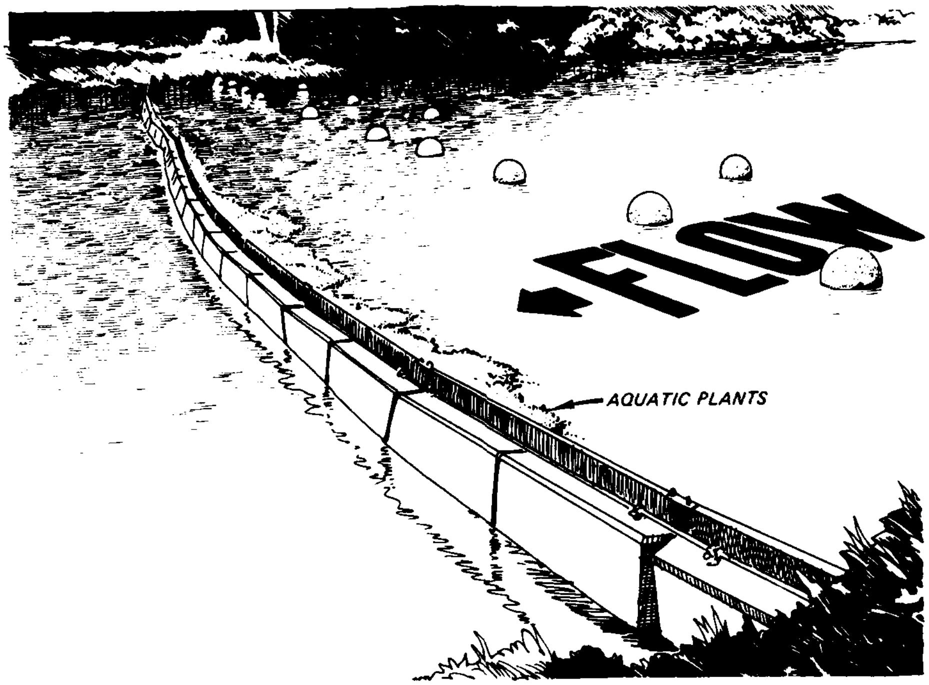


Figure 9. Schematic of an aquatic plant fragment barrier

Biological

58. Biological treatment techniques are currently applicable to four plant species--alligatorweed, waterhyacinth, hydrilla, and Eurasian watermilfoil (Sanders 1982). Miller (1984) provides guidance on using the white amur for submersed aquatic plants and the U. S. Army Engineer Waterways Experiment Station (1981) provides instructions on the use of insects to manage alligatorweed. The results of biological treatment may not be realized until several years after the introduction of the organism. However, biological treatment can be used to treat existing problem populations that are not considered

locations requiring immediate treatment. Then, the long-term benefits of biological treatment can be effectively used to reduce source populations of the problem plant at relatively negligible costs.

Environmental management

59. If the flows in a water body can be controlled and when these fluctuations in water level do not interfere with the various water uses, then lowering the water level can be an effective treatment technique by drying the plants and/or exposing them to freezing conditions (Hestand et al. 1973, Richardson 1975, Manning and Sanders 1975).

60. A second environmental management technique, placing bottom screens over submersed aquatic plants, can provide maximum reduction (Perkins, Boston, and Curren 1980). However, the initial cost of bottom screens can average $10,000 per acre, thus making the screens feasible only for small, high-use areas.

PART IV: CONCLUSIONS

61. Early identification of the problem aquatic plant population is essential in an aquatic plant management program. Annual ground surveys must be conducted to update the maps of the problem aquatic plant distribution. Without a successful monitoring program (Tasks III, IV, and V), the other tasks may become misdirected. Identifying the location of submersed plant populations is more difficult than for emersed or floating plants. Aquatic plants growing on or above the water surface are more readily identified during aerial and ground surveys (and more susceptible to treatment agents) than submersed plants. In addition, fragments from submersed plant species (e.g. Eurasian watermilfoil) are capable of floating in a flowing water system for weeks and can still remain viable. Thus, new populations can establish far from the source population (Killgore 1982). Once established, submersed plants can remain undetected for several years because they are not visible to aerial and ground surveys until they become relatively abundant near the water surface. For example, small Eurasian watermilfoil populations were discovered in a 900-acre shallow flat in the Columbia River in 1980 comprised primarily of *Potamogeton crispus*. However, Eurasian watermilfoil was not identified at this site a year before but must have become established in 1979 (or before) in order to have grown to the surface by 1980. By 1982, Eurasian watermilfoil became co-dominant with *P. crispus*. Thus, management of submersed aquatic plants requires more intensive and frequent surveys than for emersed or floating plants.

62. The size of the area affected influences the management approach. Preventing the establishment of problem aquatic plants in a relatively small water body (e.g. 50-acre lakes, farm ponds) may be a feasible goal. Once the location of problem population is identified, treatment can be implemented immediately. In large areas, however, few budgets can accommodate the treatment of all pioneer populations of a problem aquatic plant. In these cases, treatment locations must be prioritized based on treatment-related benefits to prevent the problem population impacting on the more important water uses.

63. Planning personnel may find that there is a lack of treatment options because of financial, environmental, or social constraints. If this is the case, the treatment techniques available may ultimately decide the amount of plant reduction which can be economically, socially, and environmentally

maintained. Furthermore, the number of alternative treatment techniques will usually decrease as the plant population increases, further reducing adequate treatment options. As a result, the treatment objective will have to be modified according to the available treatment techniques. Those treatments which are the most effective (and more costly) could be implemented at relatively high-use areas where the objective is to prevent water use impacts. Treatments which may pose environmental or social constraints could be used in nonuse areas to augment the program by reducing the ability of source colonies of a problem species to disperse to adjacent high-use areas.

64. A successful management program requires a continuous effort. If the program is terminated or lacks adequate funding for treatment, the problem population will usually increase with subsequent adverse impacts to the water uses.

REFERENCES

Babbie, E. R. 1973. Survey Research Methods, Wadsworth Publishing Co., Belmont, Calif.

Baker, G., et al. 1975. "Improved Application Techniques for Aquatic Herbicides," Journal of Aquatic Plant Management, Vol 13, pp 21-25.

Barko, J. W. 1981. "Comparative Influences of Light and Temperature on the Growth and Metabolism of Selected Submersed Freshwater Macrophytes," Ecological Monographs, Vol 51, No. 2, pp 219-235.

_________. 1982. "Ecology of Submersed Macrophytes," Aquatic Plant Control Research Program Information Exchange Bulletin A-82-2, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Benton, A. R., Jr. 1977. "Statement of the Impact of Submersed Aquatic Plants on Water Resources," Contract No. DACW39-77-0068, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Bitting, L. E. 1974. "Field Uses of Invert Emulsion," Journal of Aquatic Plant Management, Vol 12, pp 34-35.

Canter, L. W. 1977. Environmental Impact Assessment, McGraw-Hill, New York.

Dardeau, E. A., Jr. 1983. "Aerial Survey Techniques to Map and Monitor Aquatic Plant Populations--Four Case Studies," Technical Report A-83-1, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Dardeau, E. A., Jr., and Hogg, E. A. 1983. "Inventory and Assessment of Aquatic Plant Management Methodologies," Technical Report A-83-2, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Dardeau, E. A., Jr., and Lazor, R. L. 1982. "Implementation of the Large-Scale Operations Management Test in the State of Washington," Miscellaneous Paper A-82-7, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Dove, R. F., and Wallis, M. A. 1981. "Studies on Aquatic Macrophytes. Part XXXIV. The 1980 Aquatic Plant Quarantine Project," APD Bulletin 17, Province of British Columbia, Ministry of Environment, Victoria, B. C.

Gerloff, G. C., and Krumholtz, P. H. 1976. "Tissue Analysis as a Measure of Nutrient Availability for the Growth of Angiosperm Aquatic Plants," Limnology and Oceanography, Vol 11, pp 529-539.

Hestand, R. S., et al. 1973. "Ecological Implications of Water Levels on Plant Growth in a Shallow Water Reservoir," Journal of Aquatic Plant Management, Vol 11, pp 54-58.

Hutchinson, G. E. 1975. A Treatise on Limnology, Vol III: Limnological Botany, John Wiley and Sons, New York.

Killgore, K. J. 1981. "Eurasian Watermilfoil Treatment with 2,4-D, Diquat, and Endothall at Reduced Application Rates," Proceedings, 15th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review, 17-20 Nov 1980, Savannah, Georgia, Miscellaneous Paper A-81-3, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Killgore, K. J. 1982. "Large-Scale Operations Management Test of Prevention Methodologies: Milfoil Fragment and Diver Dredge Studies," Proceedings, 16th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review, 17-19 Nov 1981, St. Paul, Minn., Miscellaneous Paper A-82-3, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

_________. 1984. "The Use of Herbicide/Adjuvant Formulation for the Control of *Myriophyllum spicatum* L.," Technical Report A-84-__, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Killgore, K. J., and Payne, B. S. 1984. "Field Methods to Measure Aquatic Plant Treatment Method Efficacy," Miscellaneous Paper A-84-3, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Lawrence, G. R. P. 1971. The Field of Geography, Cartographic Methods, Methuen and Co., Ltd., London.

Leonard, J. M., and Payne, B. S. 1984. "Handbook for Obtaining and Using Aerial Photography to Map Aquatic Plant Distribution," Instruction Report A-84-2, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Manning, J. H., and Sanders, D. R., Jr. 1975. "Effects of Water Fluctuation on Vegetation in Black Lake, Louisiana," Hyacinth Control Journal, Vol 13, pp 17-21.

Meyer, B. S., and Heritage, A. C. 1941. "Effect of Turbidity and Depth of Immersion on Apparent Photosynthesis in *Ceratophyllum demersum*," Ecology, Vol 22, pp 17-22.

Miller, D. 1984. "Use of the White Amur For Aquatic Plant Control," Instruction Report A-84-1, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Mischon, R., and Wyatt, R. C. 1979. "A Handbook for Conducting Recreation Surveys and Calculating Attendance at Corps of Engineers Projects," Technical Report R-79-1, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Mitchell, D. S. 1979. "Assessment of Aquatic Weed Problems," Journal of Aquatic Plant Management, Vol 17, pp 19-21.

Mulligan, H. F. 1969. "Management of Aquatic Vascular Plants and Algae," Eutrophication: Causes, Consequences, Correctives; Proceedings of a Symposium, National Academy of Sciences, pp 464-482.

Muzik, T. J. 1970. Weed Biology and Control, McGraw-Hill, New York.

Newroth, P. R. 1979. "British Columbia Aquatic Plant Management Program," Journal of Aquatic Plant Management, Vol 17, pp 12-19.

Penfound, W. T. 1956. "Primary Productivity of ascular Aquatic Plants," Limnology and Oceanography, Vol 1, pp 92-101.

Perkins, M. A., and Systma, M. D. 1982. "Efficacy of Mechanical Harvesting and Its Influence upon Carbohydrate Accumulation in Eurasian Watermilfoil," Contract No. DACW39-81-M-2378, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Perkins, M. A., Boston, H. L., and Curren, E. F. 1980. "The Use of Fiberglass Screens for Control of Eurasian Watermilfoil," Journal of Aquatic Plant Management, Vol 18, pp 13-19.

Richardson, L. V. 1975. "Water-Level Manipulation: A Tool for Aquatic Weed Control," Hyacinth Control Journal, Vol 13, pp 8-11.

Sanders, D. R. 1982. "Biological Control Technology Development - An Overview," Proceedings, 16th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review, 17-19 November, St. Paul, Minnesota, Miscellaneous Paper A-82-3, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Sanders, D. R., and Decell, J. L. 1977. "A Concept for the Development of Long-Term Management Plans for Aquatic Plant Control," Miscellaneous Paper A-77-1, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Sculthorpe, W. D. 1967. The Biology of Aquatic Vascular Plants, Edward Arnold, Ltd., London.

Spence, D. H. N., Cambell, R. M., and Chrystal, J. 1972. "Specific Leaf Areas and Zonation of Fresh-Water Macrophytes," Journal of Ecology, Vol 60, pp 317-327.

U. S. Army Engineer Waterways Experiment Station. 1981. "The Use of Insects to Manage Alligatorweed," Instruction Report A-81-1, Vicksburg, Miss.

Wagner, R. H. 1974. Environment and Man, W. W. Norton and Company, New York.

Wortley, G. E. 1977. "The Use of Polymers in the Application of Aquatic Herbicides," Proceedings, Southern Weed Science Society, Vol 30, pp 345-341.

Table 1

Overview of the Tasks in an Aquatic Plant Management Procedure

Task I:	Train Personnel to Meet Management Objectives and Requirements	
	Step 1:	Become familiar with problem aquatic plant management
	Step 2:	Review laws, regulations, and local ordinances governing the use of alternative treatment techniques
	Step 3:	Organize and/or participate in aquatic plant management workshops
Task II:	Conduct a Public Awareness Program	
	Step 1:	Disseminate information material concerning potential impacts associated with the problem aquatic plant and details of the prevention management program
	Step 2:	Conduct public meetings
	Step 3:	Establish a public quarantine program
Task III:	Map Aquatic Plant Distribution	
	Step 1:	Obtain aerial photography
	Step 2:	Interpret photography and map aquatic plant distribution
Task IV:	Inventory Water Uses	
	Step 1:	Identify and characterize water uses
	Step 2:	Map water uses
	Step 3:	Determine the area encompassed by the aquatic plant populations within each water use
Task V:	Conduct Ground Surveys	
	Step 1:	Determine ground survey locations
	Step 2:	Determine time of ground survey
	Step 3:	Collect appropriate ground survey data
Task VI:	Select Treatment Locations	
	Step 1:	Identify co-occurrence of problem aquatic plant populations and water uses
	Step 2:	Rank water uses according to the quotient of the problem aquatic plant population area over the water use area
	Step 3:	Select treatment locations according to the rank of the water uses and other site-specific considerations

Table 2

Federal Regulations Governing Aquatic Plant Management

Federal Environmental Statute or Regulation	Intent or Use
	General
River and Harbor Act of 1965 (Public Law (PL) 89-298)	Section 302 authorizes a comprehensive program for the control and progressive eradication of obnoxious aquatic plant growths from navigable waters, tributary streams, connecting channels, and other allied waters of the United States in the combined interest of navigation, flood control, drainage, agriculture, fish and wildlife conservation, public health, and related purposes Establishes a 70:30 cost-sharing program
National Environmental Policy Act of 1969 (PL 91-190 as amended by PL 94-83)	Regulates the impact of man's activity on the human environment by requiring environmental assessments or environmental impact statements
Federal Noxious Weed Act of 1974 (PL 93-629)	Regulates the importation or distribution of noxious weeds into or through the United States
Project Operation, Aquatic Plant Control Program (DAEN-CWO-R; ER 1130-2-412, 1 Sep 82)	Prescribes program procedures and guidance for research, planning, and operations for the Aquatic Plant Control Program under authority of Section 302 of the River and Harbor Act of 1965 as a cost-sharing program with states
	Chemical
Resources Conservation and Recovery Act of 1976 (PL 94-580)	Directs the Environmental Protection Agency to identify which wastes are hazardous and prescribe proper methods for labeling, packaging, transporting, and disposing of such wastes (e.g., used herbicide containers)

(Continued)

Table 2 (Concluded)

Federal Environmental Statute or Regulation	Intent or Use
	Chemical (Continued)
Federal Insecticide, Fungicide, and Rodenticide Act as amended by the Federal Environmental Pesticide Control Act of 1978 (PL 95-396)	Provides for Federal control over shipment, distribution, sale, registration, labeling, and use of all pesticides, both interstate and intrastate, including requirements of pesticide applicators and exemption procedures for using herbicides not labeled for specific purposes
Federal Food, Drug and Cosmetic Act of 1971 (PL 518)	Provides tolerances for pesticide chemicals in or on raw agricultural commodities
Safe Water Drinking Act of 1974 (PL 93-523)	Sets standards for maximum contaminant levels for certain pesticide chemicals in drinking water
Pest Control Program for Civil Works Projects (ER 1130-2-413)	Assigns responsibilities and prescribes procedures concerning the use of chemicals in the Crops' Pest Control Program at all Civil Works projects. Also presents guidance for the preparation and submission of an annual pest control summary report
	Mechanical
Federal Water Pollution Control Act (PL 92-500) as amended by the Clean Water Act (PL 92-217)	Regulates the discharge of dredged or fill material into navigable waters
	Biological
Plant Quarantine Act of 1912 (PL 37-315) Federal Plant Pest Act of 1957 (PL 85-36)	Both of these acts prohibit the importation and movement of plant pests, pathogens, vectors, and articles that may harbor these organisms, unless authorized by the U. S. Department of Agriculture

Table 3

Outline of Subjects Covered in an Aquatic Plant Training Course

I. Aquatic plant ecology

   A. Taxonomy

      1. How to use a taxonomic key

      2. Scientific and common names of problem aquatic plants

      3. General characteristics of emersed, floating, and submersed aquatic plants

      4. Key characteristics of individual problem aquatic plants

   B. Habitat

      1. Critical habitat requirements of aquatic plants (e.g., temperature, water depth, substrate, nutrients)

      2. Relationship between habitat and growth rates

   C. Reproduction

      1. Sexual and vegetative reproductive structures

      2. Modes of reproduction and dispersal

      3. Rate of reproduction

   D. Effects of problem aquatic plants on the aquatic community

      1. Geographical distribution and growth rates

      2. Social, economic, and environmental impacts of problem aquatic plants

II. Elements of an aquatic plant management program

   A. Definition of training, public awareness, monitoring, treatment, and reporting

   B. Comparison of the relative level of effort, required actions, and costs of the elements applied to the different management concepts.

(Continued)

Table 3 (Concluded)

III. Problem identification and assessment for the area of interest

- A. Mapping aquatic plants
  1. Aerial photographic procedures
  2. Ground survey procedures
- B. Inventory of water uses
- C. Procedures for determining benefit/cost analysis

IV. Treatment of aquatic plants

- A. Alternative treatment techniques
  1. Chemical
  2. Mechanical
  3. Biological
  4. Environmental management
  5. Integrated
- B. Site variables which may affect treatment *effectiveness*
- C. Social, economic, and environmental ramifications of treatment

Table 4

Potential Aquatic Plant Impacts on Water Use*

Water Use	Form of Aquatic Plant Causing Impact			Aquatic Plant Impact on Water Use	Potential Result
	Emersed	Floating	Submersed		
Hydroelectric	X	X	X	Reduces the shallow storage volume of water due to increased sedimentation from senescing plants, aboveground biomass displacing water, and increased evaporation-transpiration rates	Reduced shallow storage volume results in a greater fluctuation in water surface level for a given change in inflow or outflow volume. This brings about reduced power generation due to a lower hydraulic head, thus requiring a greater rate of outflow to maintain a given power output. Because a lower head requires greater turbine flow, a loss of kilowatt/hour output may result
			X	Clogs turbine water intake pipes	Increases maintenance costs to keep intakes clear of obstruction
Flood control	X	X	X	Reduces the shallow storage volume for the same reasons stated above and restricts flow of runoff channels	Retarded runoff increases the water stage and frequency of flooding, possibly resulting in a loss of flood-protected land. To remedy the loss of storage volume or runoff channels, lower pre-flood period levels must be maintained to accommodate the design flood, complicating flow measurements and discharge capacity
Irrigation	X	X	X	Alters both the volume and the pattern of water within a gravity flow distribution network by reducing the cross-sectional area of the channel	Alteration of the volume and the pattern of water may cause higher water levels, greater evaporation, canal-bank breakage, higher seepage rates, reduced acre-foot delivery, or inadequate drainage from cropland. This could result in increased pumping costs
			X	Clogs irrigation intake pipes	Increases maintenance costs to keep irrigation intakes clear of obstruction
Potable or industrial water supply	X	X	X	Creates undesirable taste, odor, and color in water	Increases water quality treatment costs
			X	Clogs municipal or industrial water intake pipes	Increases maintenance costs to keep intakes clear of obstruction

(Continued)

* **Information partly derived from Benton (1977).**

Table 4 (Concluded)

Water Use	Form of Aquatic Plant Causing Impact: Emersed	Floating	Submersed	Aquatic Plant Impact on Water Use	Potential Result
Commercial or recreational boating navigation		X	X	Increases sedimentation from senescing plants in near-channel shallows, reducing access to boating areas	Dredging at near-channel shallows and the subsequent filling of dredge disposal sites increases operational maintenance costs for dredging and disposal. Decreased channel depth increases frictional resistance to the water, increasing fuel costs
			X	Damages propellers and clogs cooling intakes	Increases maintenance costs
		X	X	Impedes boat traffic and increases navigation hazards in the vicinity of bridges, docks, piers, etc.	Causes displacement; reduces boating use
Swimming	X	X	X	Accumulation of plants on beach is aesthetically offensive	Causes displacement; reduces swimming use
			X	Entrapment of swimmer by plant stems may cause drowning	Closes swimming area
	X	X	X	Creates undesirable taste, odor, and color in water	Causes displacement; reduces swimming use
Fishing		X	X	Interferes with angling activities and reduces access to fishing areas	Causes displacement; reduces angler use
	X	X	X	Occupies spawning areas, depletes oxygen during respiration resulting in fish kills, decreases species diversity of fish and food items (e.g., invertebrates), and creates large immature size classes of fishes resulting in stunting of both predatory and forage fish species	Decreases number of harvestable fishes resulting in reduced angler use
Hunting	X	X	X	Reduces access in hunting areas	Causes displacement; reduces hunting use
	X	X	X	Reduces water level in backwater areas and eliminates beneficial aquatic macrophytes through interspecific competition, adversely affecting waterfowl by reduction of native foods	Decreases number of harvestable waterfowl
Camping, picnicking, sightseeing	X	X	X	Decreases camping access near water margins, eliminates aesthetic view of lake, increases mosquito production, and creates a noxious odor due to decomposing plants	Reduces tourist trade due to a loss of aesthetics; causes displacement
Property value	X	X	X	Interferes with water-related uses and decreases aesthetics	Depresses property value

Table 5

Suggested Subjects Covered in Information Brochures

Description of the problem species, including taxonomy, ecology, reproduction, introduction, and distribution
Description of potential impacts caused by the problem aquatic plant
Objectives of the Prevention Management Program
Most effective treatment techniques along with the advantages and disadvantages of each
Funding of the Prevention Management Program
Participating agencies and groups
Public involvement
Addressing questions often asked by the public, including:
Will the plant go away if left untreated?
Does the plant have any economic or ecological value?

Table 6

Example of a Procedure to Rank Treatment Locations Based on Co-occurrence of Problem Aquatic Plant Populations and Water Uses

Water Use	Surface Area of the Plant Population Within the Water Use Boundaries, acres	Surface Area of the Water Use, acres	Quotient of Plant Population/ Water Use	Rank
Irrigation	1	1	1/1 = 1	1 - Irrigation
Recreational boating	100	500	1/5 = 0.2	2 - Swimming
Swimming	3	5	3/5 = 0.6	3 - Fishing
Fishing	20	60	1/3 = 0.3	4 - Lakefront property
Lakefront property	100	400	1/4 = 0.25	5 - Recreational boating

Table 7

Environmental and Administrative Factors to Consider when Choosing a Treatment Technique

Treatment	Site Variable	Considerations of Possible Effects on Treatment Efficacy or Compatibility
Chemical	Plant species/reproductive stage	Plant susceptibility to active ingredient of herbicide
	Plant biomass density	Effective application rate for different biomass and penetration of herbicide throughout the aboveground biomass
	Water current velocity	Reduced contact time of the herbicide to the plant resulting in a loss of herbicide from the treatment area
	Water depth	Dilution of the herbicide causing a noneffective concentration
	Water temperature	Herbicidal action to the plant and herbicide breakdown in the aquatic environment
	Air temperature	Loss of herbicide to evaporation
	Major ions in water	Herbicidal action to the plant, herbicide breakdown in the aquatic environment, formation of marl on the epidermis or cuticle of the plant, herbicidal absorption
	Dissolved oxygen	Herbicidal breakdown in the aquatic environment; decomposition of aquatic plants in response to herbicide treatment could create a short-term biological oxygen demand resulting in a lethal level of dissolved oxygen for fish survivorship
	Sediment	Herbicidal breakdown in the aquatic environment, herbicidal absorption, penetration of the herbicide to belowground biomass
	Nontarget aquatic organisms and facilities	Dispersal of herbicide could result in detrimental effects to fishes, invertebrates, etc. (e.g., toxicity, eliminate habitat), and could contaminate water used for agriculture, commercial, or municipal purposes
Mechanical	Plant species	Fragmentation, regrowth
	Plant biomass	Carrying capacity of machine
	Water depth/plant height	Percent removal of aboveground biomass

(Continued)

Table 7 (Concluded)

Treatment	Site Variable	Considerations of Possible Effects on Treatment Efficacy or Compatibility
Mechanical (continued)	Water velocity	Maneuverability for maximum biomass removal
	Water body shape	Maneuverability for maximum biomass removal
	Bottom topography	Underwater obstructions
	Turbidity/visibility	Locating aquatic plants for maximum biomass removal
	Wind velocity and direction	Maneuverability for maximum biomass removal
	Sediment type	Removal of belowground biomass; increased turbidity in soft bottom areas
	Shoreline development	Disposal sites
	Nontarget aquatic organisms	Eliminate habitat for some aquatic organisms and disrupt benthic organisms
Biological	Plant species	Nutritional level or food preference that affects reproduction
	Plant distribution	Dispersal and density of organism
	Air temperature	Mortality
	Water depth fluctuations	Mortality
	Water velocity	Dispersal
	Wind velocity and direction	Dispersal
	Water temperature	Mortality
	Plant biomass	Population density

Table 8

Hypothetical Examples of Cost Differences of Alternative Treatment Techniques

Treatment Objective	Alternative Treatment Techniques Available	Application Costs, $	Comments	Administrative Costs $	Comments	Cost of Treatment repetition $	Comments	Total Cost $
Location 1								
Target species: Eurasian watermilfoil Acres requiring treatment: 50 Primary water uses: recreational, boating, real estate Required effectiveness: no plants in the top 5 ft of water from June-September	Herbicide (2,4-D)	25,000	Labor, travel, herbicides, gas	5,000	Obtaining permits, locating water intakes, publicizing water restrictions	12,500	25 acres require an additional treatment because of their high density	42,500
	Mechanical harvester	45,000	Labor, travel, gas	5,000	Only acceptable disposal site is located far from harvesting site	45,000	Area requires harvesting 2 months after initial harvest due to regrowth	95,000
	Diver dredge	150,000	Labor, travel, boat to transport plants to shoreline disposal site, gas	500	Obtaining permits	None	None	150,500
Location 2								
Target species: hydrilla Acres requiring treatment: 100 Primary water uses: recreation, boating, irrigation Required effectiveness: no plants in the top 5 ft of water from April-October	Herbicide (endothall)	80,000	Labor, travel, herbicides, gas	50,000	Obtaining permits, locating water intakes, providing alternative water supply to irrigate crops during the first week after treatment, publicizing water restrictions	80,000	Area requires additional treatment because of regrowth	210,000
	Mechanical harvester	90,000	Labor, travel, gas	None	None	90,000	Area requires harvesting 3 months after initial harvest due to regrowth	180,000
	Diver dredge	300,000	Labor, travel, gas, boat to transport plants to shoreline disposal site	500	Obtaining permits	None	None	300,500
Location 3								
Target species: hydrilla Acres requiring treatment: 10 Primary water use: swimming Required effectiveness: no plants from June-September	Herbicide (endothall)	10,000	Labor, travel, herbicides, gas	2,000	Obtaining permits, publicizing water restrictions (e.g., no swimming until 48 hr after each treatment)	20,000	Two additional treatments are required due to regrowth	32,000
	Mechanical harvester	Not applicable	Will not meet treatment objective	--	--	--	--	--
	Diver dredge	30,000	Labor, travel, gas, boat to transport plants to shoreline disposal site	500	Obtaining permits	None	None	30,500

Table 9

Alternative Treatment Techniques

Treatment Technique	Form of Aquatic Plant Emersed	Floating	Submersed
Chemical-Active Ingredient			
Acrolein	X		X
Amitrole	X		
Copper			X
Dalapon	X		
Dicamba*	X	X	X
Dichlobenil		X	X
Diquat		X	X
Diuron	X		
Endothall			X
Fenac	X		
Fluridone	X	X	X
Glyphosate	X	X	X
Simazine	X		
Xylene			X
2,4-D	X	X	X
Chemical-Adjuvants (Trade Names)			
Asgrow 403 inverting oil	X	X	X
Big Sur	X	X	X
Bivert	X	X	X
Diesel oil	X	X	X
Foam spray	X	X	
Formex	X	X	
Nalquatic	X	X	X
Nalco-Trol	X	X	
Nalco-Troll II	X		
Rhodia spreader-activator	X	X	
SA 77	X	X	
S-120 inverting oil	X	X	X
Spray Mate inverting oil	X	X	X
Surfactant WK	X	X	
Visko-Rhap inverting oil	X	X	X
I-VOD	X	X	X
Xylene	X	X	X
Mechanical			
Dragline		X	X
"A" frame drag boats			X
Cutter boats			X
Fragment barrier	X	X	X
Hand removal	X	X	X

(Continued)

* Contains a combination of 2,4-D and dicamba.

Table 9 (Concluded)

Treatment Technique	Form of Aquatic Plant: Emersed	Floating	Submersed	Species
Mechanical (Continued)				
Conveyer harvesters		X	X	
Hydraulic dredge			X	
Diver-operated dredge			X	
Rototiller	X		X	
Hydraulic washer	X		X	
Biological - Insects				
Alligatorweed thrip (*Amynothrips andersonni*)	X			Alligatorweed
Alligatorweed stem borer moth (*Vogitia mallei*)	X			Alligatorweed
Alligatorweed flea beattle (*Agasicles hygrophila*)	X			Alligatorweed
Waterhyacinth weevil (*Neochetina* sp.)		X		Waterhyacinth
Agentine waterhyacinth moth (*Sameodes albiguttalis*)		X		Waterhyacinth
Moth (*Arzama densa*)		X		Waterhyacinth
Biological - Pathogens				
Fungus (*Cercospora rodmanii*)		X		Waterhyacinth
Biological - Herbivorous Fish				
White Amur (*Ctenopharyngdon idella*)			X	
Tilapia			X	
Environmental Management				
Water level fluctuations	X	X	X	
Bottom screens	X		X	
Water shades			X	

END

FILMED

3-85

DTIC